On-demand assessment of spatial and temporal variability of sediment transport parameters, Belgian and southern Dutch part of the North Sea

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Introduction

Assessing the natural spatial and temporal variability of the seabed is not straightforward. Mostly, variations are described locally, using *in-situ* depth data (e.g., Van Lancker and Jacobs, 2000; Lanckneus et al., 2002; Degrendele et al., 2010), or are derived from newly acquired current and turbidity data (e.g., Van Lancker et al., this volume). Still, in many cases the regional context is missing, and sound interpretations on the driving forces are not possible. Moreover, the envelope of natural variation is not known, and it becomes very hard to distinguish naturally- from anthropogenically-induced variability.

We anticipate by providing long-term, and statistically sound data-analyses of most relevant sediment transport parameters, relevant for the Belgian and southern Dutch part of the North Sea. As a case study we have selected the variability in bottom shear stress, as this parameter is critical in the processes that govern the natural variability in bottom morphology and sediment transport. Bottom shear stress links the sea floor to the water column as it suspends sediment; influences and is influenced by surface sediment texture, micro-bathymetry and spatial connectedness. Moreover, it directly and indirectly impacts on benthic organisms; contributes to turbulence generation, causing dissipation of wave and current energy, and to entrainment and sediment mixing. As such, it is also a relevant parameter in the placement or design of offshore structures or other human activities (Dalyander et al., 2013).

Belgium proposed bottom shear stress as an indicator of changes in hydrographic conditions to assess Good Environmental Status within Europe's Marine Strategy Framework Directive (Belgische Staat, 2012). Under perturbed conditions, this parameter will be calculated, using validated mathematical models, over a 14-days spring-neap tidal cycle. It is amongst others stated that an impact should be evaluated when: (i) There is an increase of more than 10 % of the mean bottom shear stress; and/or (ii) The variation of the ratio between the duration of sedimentation and the duration of erosion is beyond the "-5 %, +5 %" range. In this context, it is critical to know the range of natural variability, hence strengthening the need for long-term data analyses.

In this paper an overview is provided on the methodological workflow, and a case has been selected on how the data provides insight into hydro-meteorological forcing.

Material and methods

Model data

Results from a 12-year long hindcast (1999-2010) were used to assess the spatial and temporal variability of sediment transport in the Belgian and southern Dutch part of the North Sea.

Wave hindcasts for the period were obtained using the Simulating Waves Nearshore (SWAN) wave model (Holthuijsen et al., 1993; Booij et al., 1999), a third generation phase-averaged wave model, suited for modelling waves in shallow water. The model calculates in time and space, the generation of waves, their propagation and shoaling, non-linear wave-wave interactions (quadruplets and triads), white-capping, bottom friction and depth-induced wave breaking. The wave model was coupled with the results from a hydrodynamic model, to account for current refraction and for the influence of the changing water depth on the waves. The model runs on a grid resolution of about 750 m x 750 m. The boundaries for the wave model were obtained from two larger scale WAM models (WAMDIG, 1988) covering the entire North Sea. Detailed information on the wave modelling can be found in Fernández (2011) and Van Lancker et al. (2012). The currents and water elevations were obtained from two-dimensional hydrodynamic models (Ozer et al., 1996; Yu et al., 1990). A fine model, using the same grid as the wave model, was set up for the Belgian Part of the North Sea, which was coupled with a lower resolution model for the entire West-European Continental Shelf. Atmospheric data (wind speed at 10 m height above sea level), were obtained from the United Kingdom Meteorological Office.

Currents and waves were used by the sediment transport model MU-SEDIM (Deleu et al., 2004; Van den Eynde et al., 2010), calculating the total load, under the influence of the local hydrodynamic conditions. The MU-SEDIM model was improved in the framework of this project to include a more time effective method for calculating the combined wave-current bottom stresses, using the method of Soulsby and Clarke (2005). A new implementation for the calculation of the bottom geometry (ripple height and ripple length), which is important for the calculation of the total bottom roughness (including skin bottom roughness, bottom roughness from bedload and form bottom roughness), was executed based on work of Soulsby and Whitehouse (2005). The model calculates the current and wave generated ripples and takes into account their time evolution. The total load is then calculated using the Ackers-White formulae (Ackers and White, 1973), adapted for waves by Swart (1976, 1977). Model output resulted in 30 minutes time step sediment transport parameters (bottom stress, bottom geometry, total load and bottom evolution) on a 750 m grid resolution.

Statistical analysis

The spatial variability of sediment transport parameters was characterized following the method described in Dalyander et al. (2013). In this paper, the maximum bottom stress will be used as an example to illustrate the statistical analyses for all sediment transport parameters. The yearly median and half of the interpercentile range (hIPR, half the difference between the 84th and 16th percentile) were calculated. The hIPR normalized by the median value (NIPR, equivalent to the coefficient of variation for normal distributions) was used as a measure of normalized variance. The 95th percentile (i.e., the value exceeded by 5% of the observations) was used as a measure of extreme values. The same routine was also used for every season, i.e.., spring (March-May), summer (June-August), fall (September-November) and winter (December-February), and can be applied for any desired period. Extraction of results is area- or location-based.

Results and discussion

As an example of results, a case is presented on the correlation of high bottom shear stresses with dominant north-eastern (NE) wave conditions. High bottom shear stresses may evoke seabed erosion

on sandy substrates, especially when occurring over longer periods. The effect of NE conditions on seabed changes was already put forward by Van Lancker and Jacobs (2000) and Lanckneus et al. (2001), and was shown recently by Gypens (2014), investigating a 14-years dataset on multibeam bathymetry in the monitoring areas of sand extraction.

Considering the entire period 1999-2010, the highest spatial average of the yearly median bottom stress was found in 2010 (Figure 1). In that year, Gypens (2014) found a maximum number of NE wave events with significant wave heights of more than 2 m. 17 events took place, which could explain, at least in part, why the yearly median of the maximum bottom stress in 2010 was 10 % higher than in the second highest year. Highest multi-year median values in bottom stress were found on the Flemish Banks, the Belgian coastal area, the Vlakte van de Raan and off the Dutch Schouwen-Duiveland, the shallowest areas in the Belgian and southern Dutch part of the North Sea.
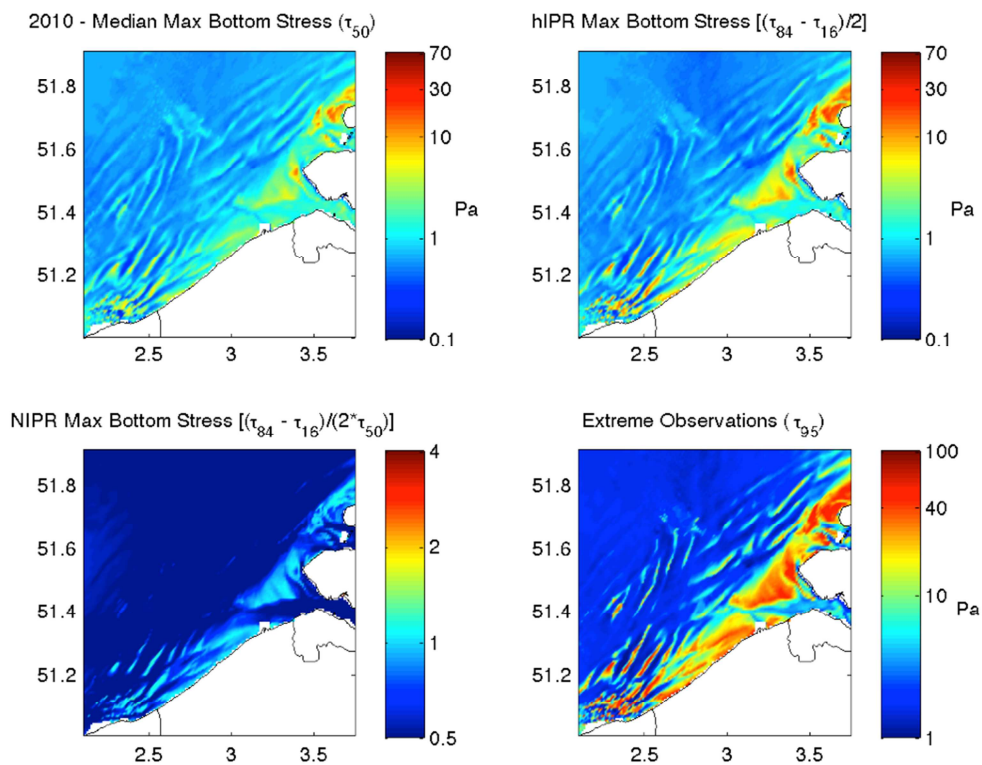

Figure 1: Median, half interpercentile range (hIPR, half of the difference between the 84th and 16th percentile), normalized interpercentile range (NIPR, half the interpercentile range divided by the median) and extreme obsevations (values exceeding the 95th percentile) of maximum bottom stress for the year 2010.

Statistical analyses revealed that higher hIPR and NIPR values (larger variability), over the same period, coincide with the areas of high bottom stress. The NIPR showed that the offshore regions were less variable. The 95th percentile of bottom stress (extreme observations) mirrored the overall spatial pattern of the median, with highest values in the coastal zone and on the Flemish, the Zeeland and Hinder banks. Seasonally, all bottom stress values were higher and had increased variability during the fall and winter months (see Figures 2, 3, 4 and 5).
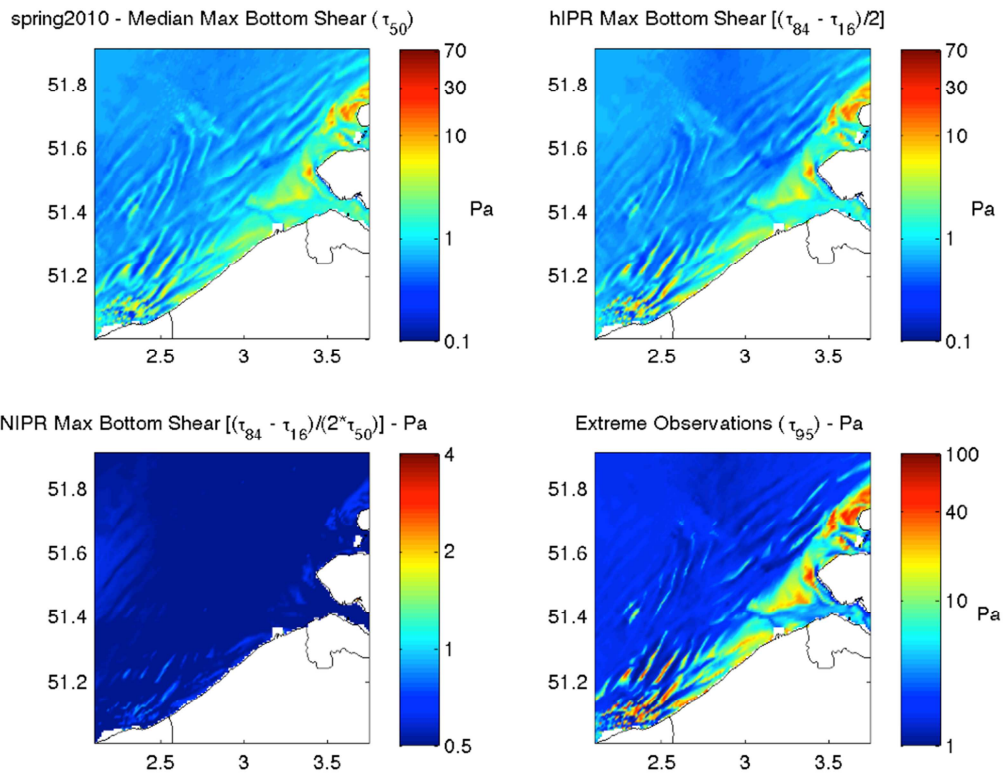
Figure 2: Spring 2010 (March – May 2010) Median, hIPR, NIPR and extreme obsevations (see Materials and Methods – Statistical Analysis for definition of the statistical parameters) of maximum bottom stress.
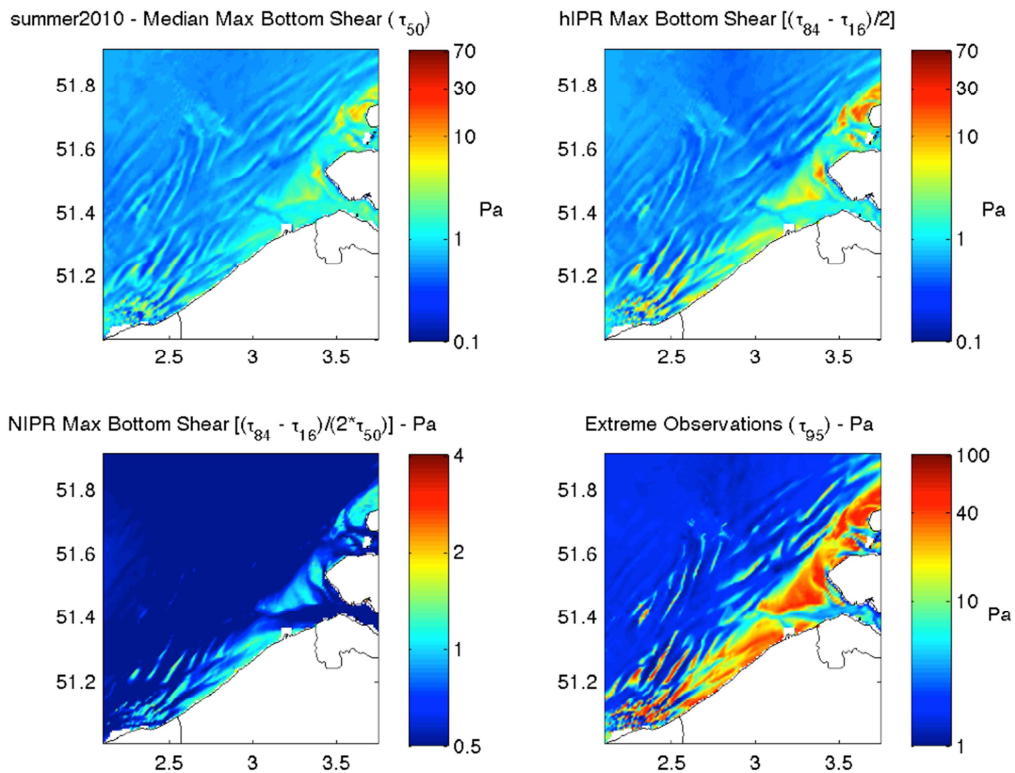

Figure 3: Summer 2010 (June - August 2010) Median, hIPR, NIPR and extreme obsevations (see Materials and Methods – Statistical Analysis for definition of the statistical parameters) of maximum bottom stress.
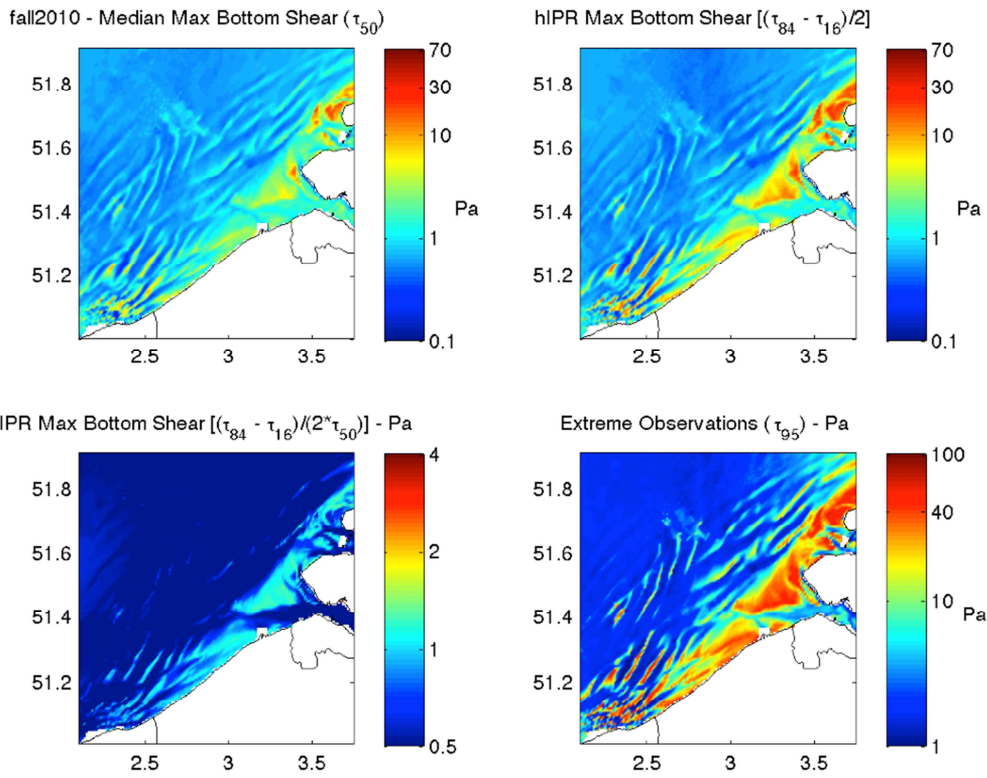
Figure 4: Fall 2010 (September – November 2010) Median, hIPR, NIPR and extreme obsevations (see Materials and Methods – Statistical Analysis for definition of the statistical parameters) of maximum bottom stress.
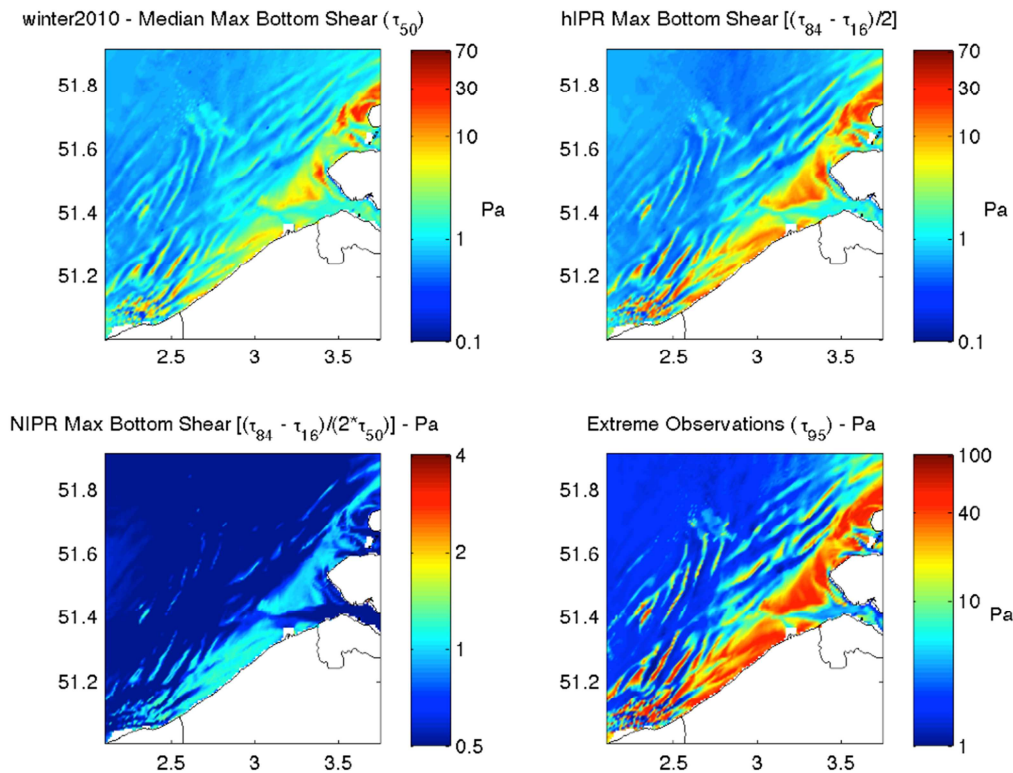

Figure 5: Winter 2010 (December 2010) Median, hIPR, NIPR and extreme obsevations (see Materials and Methods – Statistical Analysis for definition of the statistical parameters) of maximum bottom stress.

To illustrate in detail the temporal variability of the maximum bottom stress, a time series was depicted in Winter 2010 (December) as this season showed the highest variability throughout the year (Figure 6). An offshore location, on the Oosthinder sandbank (51.52°N, 2.62°E), with high temporal variability was selected. For this period a median maximum bottom stress of 6.29 Pa was calculated with values up to 60 Pa (± 10 times higher). *In-situ* data, available in the area, showed values of up to 4 Pa under normal spring tidal conditions (Van Lancker et al., this volume), hence illustrating the overall agitated conditions of Winter 2010. Most striking in Figure 5 is the correspondence of high bottom stresses with longer periods of NE wind directions.
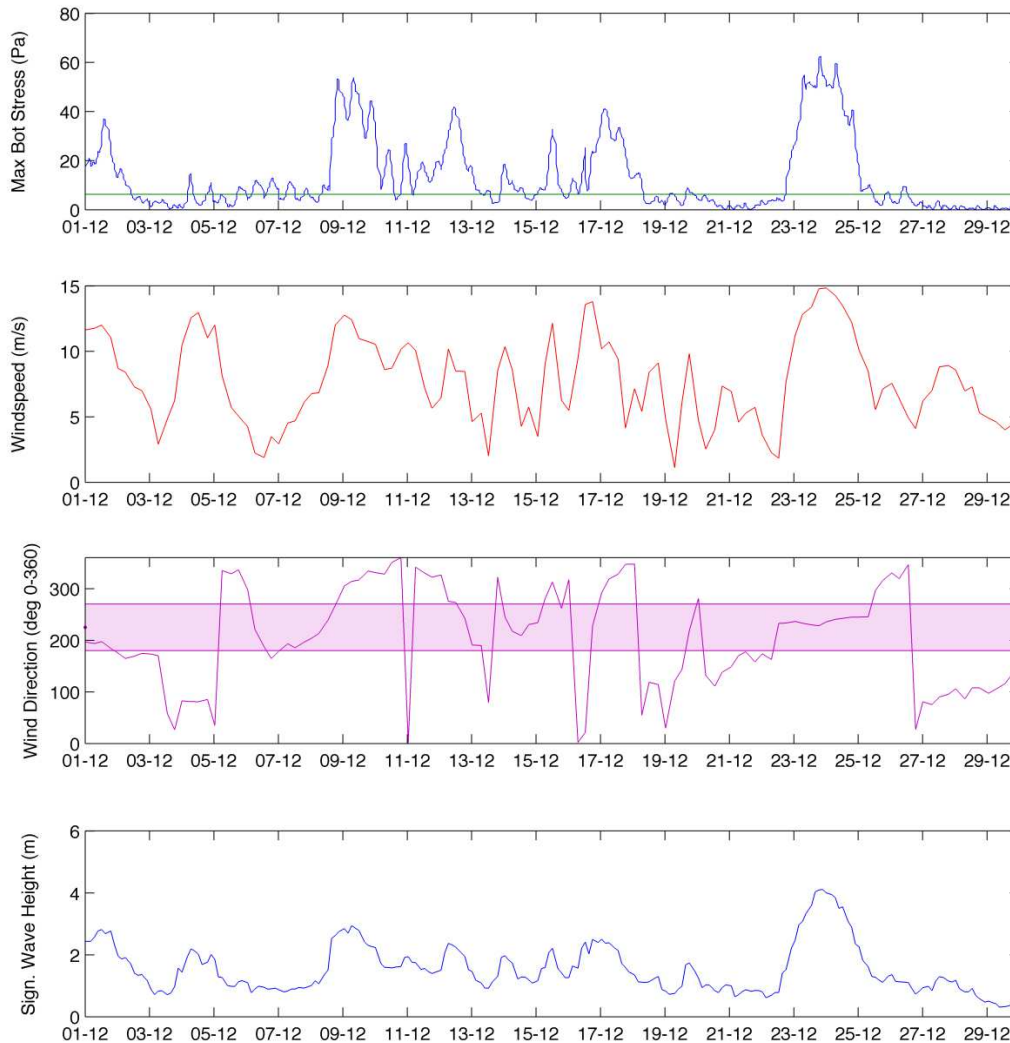

Figure 6: Winter 2010 (December 2010). From top to bottom: time series of maximum bottom stress (median value in green), wind speed, wind direction (0° wind blowing to the East, 90° wind blowing to the North - shaded area indicates NE winds), and significant wave height for a location on the Oosthinder sandbank.

Conclusions

An on-demand queryable sediment transport database has been created, covering the Belgian and southern Dutch part of the North Sea. It spans the period 1999-2010, but is expandable in time. Future applications are wide-spread and can include the estimation of the regeneration or recovery potential of the seabed, based on the natural deposition character of the area. It will also provide insight into the areas that are naturally more erosive, hence more vulnerable to the impact of human activities. With direct relevance to Europe's Marine Strategy Framework Directive, future work will concentrate also on

the development of envelopes of natural variability, critical to distinguish naturally- versus anthropogenically-induced sediment dynamics.

There is scope to develop an on-line extraction tool to easily request time series on sediment transport parameters, and its associated statistical parameters.

Acknowledgements

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